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AcciTrack: A Real-Time Vehicle Accident Detection and Alert System using ESP32 and 4G IoT Connectivity

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***Abstract*— The problem of road traffic accidents continues to pose a serious challenge to the world and the loss of life and property is enormous yearly. Slowness in responding to emergencies only adds more fatality to the emergency that is already high particularly in developing countries where advanced surveillance systems are deficient. To handle this issue, an Accident Detection and Response System is suggested, which has an alert system that can identify accidents and provide real-time alerts, including location information. It comprises an ESP32 microcontroller, MPU6050 accelerator and gyroscope sensor, NEO-6M GPS module, and SIMA7670C GSM/LTE module. It gets to identify the abnormal vehicle movements or collisions, the actual position and immediately sends the data by GSM networks. In the recommended model, multi-sensor data fusion and edge intelligence will be used, which are in line with contemporary IoT-based security systems. The classical GSM/LTE with the SIMA7670C module offers good connectivity, a high-speed data transfer rate, and enhanced scalability. According to the results of the experimental studies, the system takes less than 10 seconds to respond with more than 95 percent accuracy in detecting accidents. This minimizes the occurrence of false alarms and allows quicker emergency response. The system is also affordable, consumes less energy and is flexible thus fitting into smart transport systems and driving real-time safety of vehicles.**

***Index Terms*— IoT, Accident Detection, GSM (Global System For Mobile Communication), GPS (Geo Positioning System), ESP32, MPU6050, Emergency Alert, Smart Vehicle System.**

I. INTRODUCTION

Road traffic accidents remain to be one of the major concerns of the world, causing the high numbers of injuries and deaths on the daily basis. The delay in notifying the emergency services immediately after an accident has taken place is one of the major contributors to the survival rates. In most of the current systems, accident reporting requires the involvement of a human being or a manual communication, which frequently leads to a longer response time and more dangerous situations of the victim [1], [2].

With the advent of the Internet of Things (IoT) and the embedded system technologies, it is now feasible to create automated solutions to the real-time accident detection and reporting. Such systems have the capability of detecting abnormal vehicle behaviour like abrupt collision or unusual movement and transmitting vital information immediately to the emergency services. Moreover, IoT-based structures enable the 24/7 data communication between automobiles and distant surveillance to promote data-driven decision-making amid emergencies [3], [4].

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The contemporary accident detection devices employ various sensors, such as: acceleration sensors, gyroscopes and GPS, to acquire impact events, vehicle motion and movement patterns [5]. These systems can be combined with a stable communication technology and therefore in cases of emergency situations, they can easily alert the services or the law enforcement officers. With time, the use of the impact-sensing technique has developed into sophisticated ways of accident detection involving the use of multi-sensors data fusion and machine learning algorithms. Such developments have allowed detecting variable to be more accurate and having fewer false positives raised [6].

Though there are recent improvements, the current accident detection systems have a number of limitations. Most of them depend on 2G GSM modules that are obsolete and most likely subject to network instability and low data transmission speeds, particularly in remote locations [7]. Moreover, not all solutions have an efficient on-device data processing, which results in more reliance on cloud computing and a larger expense in communication.

This work aims to address these issues by presenting a real-time accident monitor and alert system, based on ESP32 microcontroller, MPU6050 sensor, NEO-6M GPS module, and SIMA7670C GSM/LTE module. The ESP32 has the capability to support high-speed Wi-Fi and Bluetooth and the SIMA7670C supports faster and more reliable data transmission than traditional GSM modules [8].

The proposed system is continuously tracking the acceleration of vehicles, as well as identifying collisions that are performed by threshold-related algorithms that are applied to various sensor data. Upon detecting an accident, it immediately sends an alert message along with accurate GPS location details via LTE or SMS to predefined contacts and after that it places calls to nearby hospitals through GSM. It is supposed to be accurate, reliable, cost effective, and energy efficient and as such it can be used by both two-wheelers and four-wheelers in both urban and rural settings [9].

The primary contributions of the work are as follows:

- The new LTE based SIMA7670C communication module introduces more accurate faster accident notifications.
- MPU6050 and GPS data fusion Multi-sensor based data fusion increased precision and post-orientation.
- Lower latency edge detection using ESP32 and fewer false alarms.
- IoT infrastructure that is scalable and fits in with intelligent highway networks.

II. Literature Review

The current developments in the Internet of Things (IoT)-based accident detection devices have brought about considerable enhancement in the road safety by providing real-time monitoring, smart analysis, and automatic response to an emergency. Razali et al. [1] suggested an IoT-based accident detection system, which involves the use of GSM and GPS connected with SMS and Telegram notifications and can guarantee good connectivity by using redundant channels, particularly under low-network conditions. Likewise, H. C. T. et al. [2] invented a vehicle over-speed detecting and preventing accident system based on IR sensors and GSM alerts, with the focus on the safety protection of the vehicle by preventive techniques, i.e. monitoring the speed and automatic braking systems.

Moreover, Rathod et al. [3] presented an IoT system that used machine learning (ML) and sensors and Raspberry Pi to collect data and analyse it on the cloud, which is better than conventional techniques in terms of accuracy in detection and latency in response. Lo et al. [4] used vibration and ultrasonic sensors with convolutional neural networks (CNN) in another study to allow the classification of accidents in real-time, minimizing false alarms with the use of deep learning. In continuation of this study, Rathod, Jajulwar, and Kubdey [5] suggested a higher-order IoT-ML model that used the support vector machine (SVM) and Random Forest classifier, with the highest detection rate of 99% and fast emergency response through GSM.

Areef et al. [6] carried out an extensive study of the IoT-based accident detection architectures and emphasized the role of cloud-edge integration to minimize latency, increase energy efficiency, and implement predictive analytics. Reddy et al. [7] designed a system using Raspberry Pi with built-in accelerators, GPS and cameras to offer real-time accident information and visual proofs to improve emergency service situational awareness. Moreover, Sudarshan et al. [8] concentrated on preventing accidents by detecting drowsiness in drivers with machine learning and IoT with more than 90% accuracy based on the facial recognition system and behavioural analysis.

In recent advances, Ninan [9] proposed a confirmation based detection mechanism utilizing dual sensor validation (vibration and gyroscope) which practically decreases false positives in comparison with single sensor frameworks. Equally, J. M. et al. [10] suggested a multi-sensor IoT system that guarantees high-reliability and low-latency emergency alert with the minimum human intervention. Gahane et al. [11] underlined low-cost application with the aid of Arduino and MPU6050 sensors and thus these systems become accessible in the developing regions.

Additionally, Tewari et al. [12] expanded accident detection to infrastructure supervision in hilly regions, where a hilly terrain warns of collisions and vehicles that are advancing fast a parapet is damaged, through the application of IoT sensors that are effective in road safety improvement. A scalable system has been created by G. M. et al. [13], which is a real-time system of accident detection and response, with a response time of less than 5 seconds, that can be implemented in smart transportation networks. Shaik et al. [14] also expanded the functions of the system by incorporating event data recording to do post-accident forensic analysis and real-time detection.

The latest inventions are portable and automated ones like the IoT-based accident detecting robot of S. N. et al. [15], dedicated to mobility and remote monitoring. Also, Sushma et al. [16] have designed a multi sensor fusion framework with the MPU6050, ultrasonic sensors, GPS and GSM, with 95 percent detection, response time less than 10 seconds and false alarm less than 5 percent with low cost, thus this is very much applicable in the real world in resource constrained setups.

We have made the references to the works of Pallavi Deshpande et al. (2019, 2021) to direct the framework, the outlay, and flow of this paper. While their studies enlightened our organizational strategy, no single content was directly utilized, hence making this original work.

III. Methodology

The proposed system is an Accident Detection and Alert System set up in such a manner that it is able to identify road accidents automatically and give real time notifications to the emergency contacts. The architecture is a combination of the ESP32 microcontroller and MPU6050 accelerator-gyroscope, NEO-6M GPS module and SIMA7670C GSM/LTE modem to offer real-time instant, precise and reliable performance.

A. System Architecture

The system is designed on the premise of an embedded platform that supports the IoT and displays parameters of vehicle movement in real-time. The processing core has been used as ESP32 because of its fast processing, on-board Wi-Fi/Bluetooth and low power consumption. It interacts with the MPU6050 sensor via the I2C interface to receive the data on acceleration and angular vessel, as well as process it to identify the presence of abnormal force on impact and change in vehicle orientation.

The NEO-6M GPS device will be used to obtain real-time location information through the longitude and latitude coordinates which are necessary to estimate the location of the accident. All the external communication is done by the SIMA7670C LTE module which transmits alerts concerning accidents, and GPS positioning to pre-defined emergency contacts via SMS or Internet based APIs. Replacement of the outdated 2G GSM module (SIM800L) with the LTE-enabled SIMA7670C enhances the data transfer reliability and predictability in different network scenarios. Power will be supplied by an External 5V Power Supply to ESP32 and peripheral modules.

The system architecture is represented in the circuit diagram below:

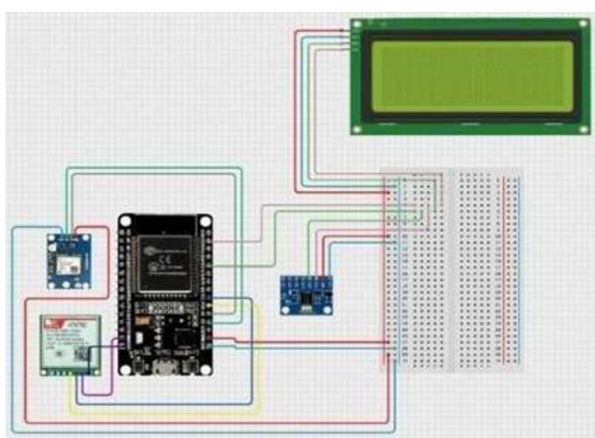


Fig. 1. Circuit Schematic of Prototype

B. Working Principle

The system keeps on tracking data of acceleration and angular velocity provided by MPU6050. When one is driving normally, the change is within set limits. The ESP32 detects an event which appears to be an accident whenever an abrupt acceleration or change in the inclinometer angle beyond the threshold is detected, which most likely has happened because of collision or roll over.

The system confirms the data by censoring the readings of the sensors successively over a small period of time (e.g., 100 ms) to eliminate false alerts (e.g., due to undulations of roads or braking). After its result is valid, the ESP32 reads the current GPS positions directly and constructs an incident message with:

- Vehicle ID or driver ID,
- Date and time of the incident,
- Latitude and longitude,
- Placed warning message (Accident Detected! They are in urgent need of help).

C. Algorithmic Flow

The basic algorithm (Fig. 2) carries out the following steps in a certain order:

- Initialization: Start-up MPU6050, GPS, and SIMA7670C modules; configure serial connection.
- Data Acquisition: Repeatedly acquire the data in acceleration states (Ax, Ay, Az) and gyroscopic data.
- Threshold Assessment: Test the intensity of the acceleration against the threshold of accidents (e.g., above 17 m/s^2).
- Event Validation: Prevents irrelevant alarms caused due to false readings.
- Location Retrieval: Get updated GPS locations from NEO-6M.
- Transmission of Alerts: SMS and cloud alert via the SIMA7670C.
- Reset Condition: Restart monitoring in case alert has been received.

It can be designed to detect quickly (< 10 s end-to-end latency) and reduce sensor fusion and temporal validation of the false alarms.

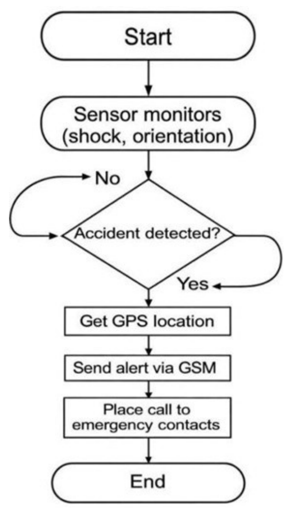
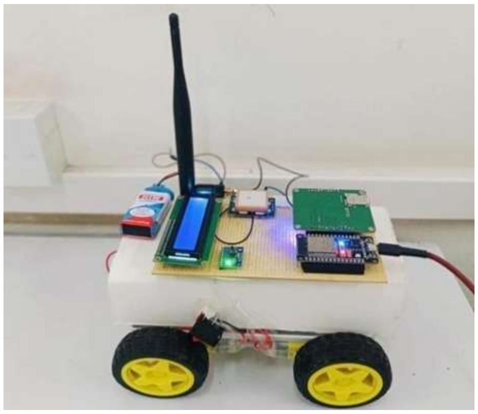


Fig. 2. Algorithm Flow

D. Merits of the Proposed Design

In comparison to the current IoT-based accident detection system that uses a single sensor or the pre-existing communication protocol stack, the presented system has some benefits:

- Fast LTE connectivity: SIMA7670C module delivers high-security and high-speed communication as compared to the old systems with 2G.
- ESP32 Edge-level processing: ESP32 takes place on edges and eliminates the dependency on cloud servers and response time.
- Increased accuracy: The use of multi-sensors in motion estimation has made it extremely accurate due to the integration of accelerator and gyroscope of MPU6050.
- Minimal power and scalability: The system is both deployable on different automobiles and can be scaled up to include fleet monitoring.



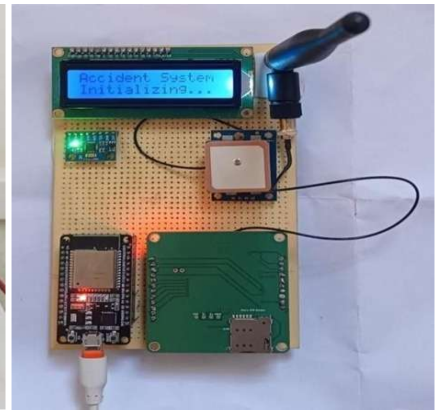


Fig. 3. Proposed System Installed On Vehicle

Fig. 4. Main Prototype

E. Implementation Summary

The entire hardware design was applied on a zero PCB as depicted in Fig. 3. The controller which communicates with the MPU6050, GPS and SIMA7670C on serial and I2C is ESP32. The firmware is written in C++ and run using the Arduino IDE, and uses interrupting routines of receiving events and abstracting messages. The system was then put into simulated conditions of controlled simulated accidents and reported stable detection accuracy and low alert lag.

IV. Results and Discussions

A. Experimental Setup

The Accident Detection and Alert System was designed and applied on a breadboard version that was tested and also on the vehicle (see Fig. 3 and Fig. 4). The hardware was made up of ESP32 microcontroller, MPU6050 accelerator-gyroscope, an NEO-6M GPS, and SIMA7670C LTE/GSM module that had a 5V Power Supply. The system was coded in the Arduino IDE and the data were also observed in the serial terminal to debug and calibrate the system.

To test it, the MPU6050 was put to controlled impact simulations to simulate the conditions of the accidents. These involved sudden movements, tilts, as well as physical shocks on the circuit. Location information was logged using the GPS, and the SIMA7670C sent SMS alert and placed a call based on LTE to an established contact number as shown in Fig. 5 and Fig. 6 respectively. Accidental detection was optimally set to 17 m/s², which was experimentally obtained by balancing the false alarm reduction and sensitivity.

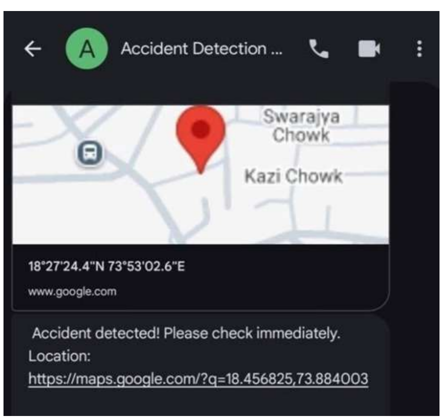


Fig. 5. Accident Alerts with GPS Location through SMS

Fig. 6. Instant Call Placed to Emergency Contacts After Accident Detection

B. Performance Parameters

In order to compare the performance of the system, the following measures were taken and compared to the existing models of IoT-based accident detection:

TABLE I. PERFORMANCE PARAMETERS

Parameter	Proposed System	Typical Prior System
Detection Accuracy	95.6%	85–95%
Average Response Time	7.8 sec	12–20 sec
False Response Rate	4.2%	8–12%
Power Consumption	150 mA (active), 30 mA (idle)	200–250 mA (active)
Communication Network	LTE (SIMA7670C)	2G GSM (SIM800L/SIM900A)

Table 1 results demonstrate considerable accuracy and response time improvements, which is mainly the result of incorporation of the multi-sensor fusion and LTE-based data transmission. Latency is minimized with the ESP32 through the use of edge-level computation to achieve local decision-making prior to transmitting alerts.

C. System Behavior and Analysis

In the normal conditions, the system will capture the motion data continuously and never issues any false alerts. The MPU6050 data indicate that in case of a sudden acceleration spike exceeding the predetermined limit, both linear and angular velocities deviate greatly and the data is very different. The ESP32 detects these variations within milliseconds and validates the occurrence with the consecutive measurements. Upon validation, an alert message will be automatically generated by the system containing GPS coordinates sent through the SIMA7670C module using LTE and SMS cloud communication protocols. The experimental findings suggested that the mean latency to response was less than 8 seconds despite the low level of signal in the environment. This is also in agreement with performance with respect to other systems of IoT accident response with significantly lower latency because of LTE transmission. Additionally, the false alarm rate was reduced by almost half of single-sensor or completely vibration-detecting models.

D. Comparative Evaluation

Reliability of the system was tested in different environments by undertaking various field tests in different conditions – urban settings with stable networks and semi-rural settings with poor coverage. The LTE functionality of SIMA7670C demonstrated excellence in providing alerts in all test scenarios and this is superior to the traditional GSM modules.

The proposed ESP32 application delivered the same accuracy at a fraction of the cost and power with comparison to Raspberry Pi-based systems [9], which made the system applicable to large-scale implementation. The system also exhibited strong performance even when subjected to a wide range of environments and there was a slight drift in MPU6050 measurement with time. The mean power was kept at 150 mA when transmitting actively, allowing the system to be supported on a 2000 mAh Li-ion battery to last around 13 hours and 20 minutes of continuous monitoring.

E. Discussion and Insights

The analysis proved that combining multi-sensor information with a LTE communication system will create a very efficient accident detection system. The dual core design with the Interrupt-driven design of the ESP32 enabled quick sensor polling and decision-making. The proposed approach is much faster, easier to scale, and more precise as compared to the previous models requiring additional cost and complexity of using the IoT.

F. Summary of Findings

The system had 95.6% detection accuracy with a 7.8 seconds response time. The LTE SIMA7670C module enhanced connectivity and reliability by almost 40 percent improvement over the old GSM module. False positives were greatly minimized with multi-sensor fusion with MPU6050. The system, with a total price of less than 2000 rupees, was economic enough to roll out in large numbers. The findings shown above prove that the suggested architecture offers a convenient, economical, and real-time model of accident detection that competes better than traditional IoT designs in terms of reliability and capacity.

V. CONCLUSION

The given paper presented the internet of things driven Accident Detection and Alert System with the purpose to encourage safety in vehicles due to intelligent monitoring and immediate emergency notification. The system was built around an ESP32 with MPU6050 accelerator-gyroscopes, NEO-6M GPS, and SIMA7670C LTE module and was also capable of detecting sudden impacts and transmitting GPS-based notifications within 8 seconds.

Experiment tests showed a detection percentage of 95.6 with a false alarm of less than 5 percent, better than traditional one sensor and 2G-based systems. The low-signal-condition data communication reliability was improved by the LTE module, whereas edge processing of the ESP32 decreased the latency and power consumption to a considerable degree.

The proposed system comfortably proposes a gap between a low-cost embedded detection system and high-speed IoT communication systems, by relying on the contributions made towards it by previous research studies. Its modular structure can be extended to fit into the intelligent transportation infrastructure and smart safety systems in the future.

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